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The
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IRON ORES OF PENNSYLVANIA

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IRON ORES OF PENNSYLVANIA

By WILLIAM O. HICKOK, IV

Part I

INTRODUCTION

Frequent inquiry has been made of the Geological Survey about iron ores, their utilization, and value. The last comprehensive report on Pennsylvania iron ores was written many years ago and changing conditions of transportation, blast furnace practice and beneficiation of iron ore have completely reorganized iron ore mining since then. Recent available reports deal with the origin and mineralogical characteristics of individual deposits but do not consider economics or production.

This report summarizes the history of iron ore production in Pennsylvania and the changing economic conditions which affect the industry and control its future. The geological environment, mode of origin, and future reserves of the various types of iron ore are discussed. In addition a brief summary is given of the iron ore resources of various regions outside of Pennsylvania that compete with Pennsylvania ores at present, or probably will in the future.

HISTORICAL OUTLINE OF THE IRON INDUSTRY

Previous to 1815 land transportation was so expensive that iron ore mining and smelting went hand in hand and the old time charcoal and anthracite furnaces and forges were located near the iron ore deposits. As a result the iron industry was concentrated in the States containing the ore deposits. The advent of railroads, however, permitted taking the ore to the fuel and this determined the location of later blast furnaces. Since Pennsylvania had an abundant supply of both iron ore and fuel, it became an important center for iron making and has remained so.

The New England colonies and Virginia, which were settled before Pennsylvania, developed an extensive iron industry before the first Pennsylvania furnace was built in 1716. However, once started, the Pennsylvania iron industry grew rapidly because of the abundance of high grade iron ore and wood suitable for making charcoal, so that by the Revolutionary War period, Pennsylvania had assumed a dominant position in the iron-smelting industry of North America.

The discovery of anthracite and its advantages for iron smelting soon made eastern Pennsylvania the center of a thriving iron industry equal to or greater than that in all the rest of North America.

Soon after 1850 fundamental changes swept the iron industry of the world. The building of railroads supplied inexpensive transportation for the raw materials of the iron industry even from great distances to convenient central points. The discovery of coke made from bituminous coal and its superiority for blast furnaces, released the iron industry from the anthracite regions. The discovery, slightly

later, of enormous iron deposits in the Lake Superior region gave a new and larger source of iron ores. Then the exhaustion of the richer and more cheaply mined Pennsylvania brown-iron ore deposits shifted the iron industry from the Atlantic coastal regions to west of the Appalachian Mountains.

Transportation of iron ore long distances for a few dollars a ton has made it cheaper to use high grade ore from a distance than low grade ore mined nearby. Low grade ores cost more to smelt because they require more flux and fuel besides the cost of removing large amounts of slag.

Although the iron industry no longer depends on anthracite and uses mostly iron ore from the Lake Superior region, Pennsylvania still leads as a producer of pig iron, owing to an abundance of high grade coking coal in western Pennsylvania. Pennsylvania has maintained first place as a pig-iron producer though supplying only two percent of the iron ore mined in the United States.

CLASSIFICATION OF IRON ORE

Iron ores are commonly divided into four classes: Hematite, Brown-iron ore (limonite), Magnetite and Carbonate. The class names refer either to the chief iron mineral of the ore, the color, or the chemical composition. In spite of the differing criteria for classification, the groups are mutually exclusive and will be discussed individually.

HEMATITE DEPOSITS

Hematite occurs in Pennsylvania mainly in the Clinton formation of Silurian age; less in the Chemung formation of Devonian age, in Tioga County. It is of sedimentary origin, formed by the chemical deposition of iron oxide from water much as some limestone is formed. This ore is always high in lime as it in part consists of iron replacing sea shells interbedded with shale and sandstone. The Clinton formation lies in the Silurian system which has been divided in Pennsylvania as follows:[1]

Upper Silurian (Cayuga) series	
Tonoloway group	*limestone and shale*
Wills Creek group	*calcareous shale*
Bloomsburg group	*red shale and sandstone*
Middle Silurian (Niagara) series	
Lockport group	*limestone*
Rochester group	*sandstone ("upper ore sandstone")*
Clinton group	*green and red shale, red sandstone, iron ore*
Lower Silurian (Medina) series	
Tuscarora group	*massive hard grey sandstone*
Juniata group*	*red shale and sandstone*
Oswego group*	*hard grey sandstone*

[1] Ashley, George H., A syllabus of Pennsylvania geology and mineral resources: Pennsylvania Topographic and Geologic Survey, Bull. G-1, 1931.

* The Juniata and Oswego groups are now thought to be of Ordovician age.

Clinton ore occurs in Snyder, Mifflin, Juniata, Blair, Huntingdon and Bedford Counties, as three or four thin beds ranging in thickness from a few inches to more than two feet. The length of outcrop is very great because of the intricate folding of the Silurian rocks. Mining has been confined mostly to stripping soft ore, though some underground drift mining on the hard ore has been done. The total tonnage available is probably quite large. In 1909, when 20,000 tons per year were being produced, it was estimated that about 5,000,000 tons were available.[2]

In central Pennsylvania Clinton iron ores commonly outcrop high on mountain slopes, because of their position above the Tuscarora sandstone, which is a persistent mountain-forming rock in this State. The ore beds are seldom over two feet thick and the grade is low. This combination prevents mining the ores at present, but they will be mined again when the value of iron ore is materially increased.

The analyses show the grade of the Clinton iron ores. The ore is "soft" or "hard." The soft ore, found near the surface or at intersecting faults, seems to have been formed through leaching of the hard ore by ground water and is commonly of higher grade than the hard ore.

*Analyses of Clinton iron ores**

A. S. McCreath, Analyst

	1	2	3	4	5	6
Fe	33.80	40.90	23.00	27.25	46.90	50.50
$CaCO_3$	39.14	18.14	31.27	36.01	—	—
$MgCO_3$	2.50	1.41	4.08	1.18	—	—
Insoluble residue	3.85	12.98	25.39	16.61	22.88	15.22
Sulphur	.004	.014	.054	—	.005	.024
Phosphorus	.358	1.018	.268	.203	.310	.257

1. Hard ore—Danville bed, Winfield, Union County. F. p. 6
2. Hard ore—Sand vein, Matilda Furnace, Mifflin County. F. p. 100
3. Hard ore—Sand vein, Matilda Furnace, Mifflin County. F. p. 100
4. Hard ore—Ore sandstone, Blacklog Gap, Huntingdon County. F. p. 134
5. Soft ore—Sand vein, Logan Gap, Snyder County. F. p. 18
6. Soft ore—Bird-Eye vein, Freeburg, Snyder County. F. p. 27

BROWN IRON ORE

The brown ore deposits of Pennsylvania consist of bog ore deposits, and residual limonite or "brown hematite" deposits, the latter yielding most of the commercial brown ore.

Bog-iron ore deposits furnished all the brown ore mined in recent years in Pennsylvania but are of little importance in the iron-smelting industry except where they are mined for their manganese content. These deposits, found mainly in the northern part of the State in swamps or just under the surface of flats that were former swamps, are formed through the deposition of iron from the sluggish water of ponds and swamps and are generally mixed with sand, clay

[2] Papers on the conservation of mineral resources, U. S. Geological Survey Bull. 394, 1909, p. 88.

* Pennsylvania Second Geological Survey, Report F.

and plant roots. The bog ores are used at present only for removing sulphur from natural gas. For details of the bog-iron ore industry and methods of locating deposits and mining them see bulletin No. 59 of this Survey.[4]

The residual limonite deposits, at one time the chief source of iron in Pennsylvania, are not of commercial importance at present. In the Appalachian province they have been divided in order of importance into valley ores and mountain ores. The valley ores appear as irregular, shallow pockets or as scattered lumps in clay, derived from the decomposition and solution of the Cambro-Ordovician limestones and dolomites. Most of the deposits which are mixtures of hydrous iron oxides (limonite) and clay lie within 50 feet of the surface and are soon exhausted.

The mountain ores are more variable in occurrence and appearance. They have been formed by leaching of iron-rich shales, sandstones, or thin limestones or iron-carbonate beds, and are commonly elongated parallel to the strike of the rocks and confined to the surface zone of weathering.

Stratigraphically the brown ores are associated with rocks from pre-Cambrian to Carboniferous. Pre-Cambrian ores occur in the gneisses and schists of southeastern Pennsylvania in small, scattered deposits. They were worked in the early days but have little to offer for the future. The ores associated with the great Cambro-Ordovician limestones, which underlie the Chester, York and Lancaster valleys, the south half of the Kittatinny valley, the Nittany and other smaller valleys, occur mainly at the base of the limestone at its contact with the underlying quartzite (Chickies), (mountain ores and high silica ores) and in the lower part of the limestone series (Waynesboro formation), with a few scattering deposits elsewhere. The location of these horizons is shown on the new State geologic map. Both horizons have yielded ore in the past and will doubtless be the principal sources of brown ore in the future. Many deposits not on these lines are due to iron-bearing waters which rose along the fault planes.

In the Silurian several "iron sandstones" have been the source of small amounts of ore. Unimportant ores occur in the Lower Devonian. A carbonate ore in the Marcellus, weathered to limonite, has been extensively mined in central Pennsylvania where it is locally 15 to 20 feet thick and has been mined to a depth of 100 feet. This ore may have large future value. Brown ores of Carboniferous age are confined mainly to the top of the Vanport limestone (buhrstone ore), resulting from the partial replacement of that limestone by waters bearing iron leached from the overlying shales. The ore is confined to the zone of weathering. The hilltops of western Pennsylvania have been benched for many miles by the working on this bed. This bed is of course confined to the counties containing the Vanport limestone, in general the lower Beaver and Allegheny River drainage area.

Several Pennsylvania brown-ore mines are well known for their

[4] Corbin, J. Ross, Bog iron ores: Penna. Topo. & Geol. Survey, mimeo. bull. 59, 1922.

large size, long continued production and excellent ore. The Chestnut Hill mines on the contact of the Chickies quartzite and Cambrian limestone in West Hempfield Township, Lancaster County, mined 25,000 tons a year for many years. At its best the Scotia ore bank in Centre County produced 1,200 tons of iron ore a day. The Pennington and other mines in Franklin Township, Huntingdon County, yielded over 1,000,000 tons of brown ore from the Cambro-Ordovician limestones. Iron mining started early in Lehigh County with very large mines but near Ironton several operators mining a single ore body excavated a pit over half a mile long and a quarter of a mile wide.

In a few instances rich brown ores were mined and shipped without being concentrated and were classed as lump ore. More commonly much clay and sand mixed with the ore had to be removed before shipment as wash ore. Such beneficiation requires little equipment and adds little to the low cost of digging because of the unconsolidated state of the ore.

MAGNETITE

Magnetite for a great many years has constituted the bulk of Pennsylvania iron ore production. Although two types of deposits have been worked, only the Cornwall type is at present of commercial importance. It is of contact metamorphic origin and Triassic age. The second type, of pre-Cambrian age, is associated chiefly with the granitic gneisses in South Mountain, Berks and Lehigh Counties, and rarely with the serpentine in the southeastern corner of the State. The Triassic deposits will be discussed at greater length because of their present and probable future economic importance.

Pre-Cambrian magnetite deposits.

The magnetites of the pre-Cambrian rocks can be divided into two groups, according as they are associated with the igneous gneisses of the pre-Cambrian belt, stretching from south of Easton to Reading, or with the serpentine belt in the southeastern corner of the State. Small bodies of magnetite have been found in the serpentine, in serpentine quarries and chromite mines. The magnetite can be separated in mining and used for iron ore, but because of the scattered nature of the ore pockets, and their small size, it is doubtful if such mining will be found profitable.

The South Mountain magnetites on the other hand will undoubtedly form part of the iron ore resources of the future. The deposits occur throughout the belt of pre-Cambrian rocks stretching eastward from Reading. In Pennsylvania the belt is about 60 miles long with a maximum width of 20 miles. The outcrop widens in New Jersey and the rocks contain several iron deposits which have been thoroughly studied by Bayley.[4] In Pennsylvania the iron mines are

[4] Bayley, W. S., Iron mines and mining in New Jersey: New Jersey Geological Survey, vol. 7, pp. 89-193, 1910.

smaller and never have been extensively developed. The ore is in several parallel veins or zones running east-west through the pre-Cambrian igneous gneisses, following the banding of the gneiss, locally cutting across it and even transgressing the boundary between two types of gneiss. Nowhere have magnetite veins been found in the sedimentary gneiss or marble of the pre-Cambrian. Miller[5] thinks that the ore deposits were formed by injection of aqueo-igneous solutions into the igneous gneisses as they were cooling. The solutions are thought to originate by means of magmatic differentiation in the deep-seated part of the same magma. With such an origin the magnetite veins should extend well below the limit to which it would be profitable to mine them.

The ore is low grade; an average of all the analyses made of the ore from the Allentown quadrangle shows Fe 42 percent, SiO_2 35, P 0.054, S 0.07, and Mn 0.01 percent. The average titanium content of the ore is not known, but in some mines it is high and in others it is low. The veins range in width up to 15 or 20 feet, generally being about 8 to 10 feet wide. They all descend at a fairly steep angle, making underground mining necessary. The ore is abundant; a small area near Vera Cruz was surveyed magnetically by Tobias Castelane under the direction of Thos. A. Edison, who calculated that the area mapped contained about 20,000,000 tons of low-grade ore above water level.

In the past fairly large sized mines have been developed in the pre-Cambrian magnetites, and although not as large as mines in the Triassic deposits, several of them have produced considerable ore. The Seisholtzville mines, one mile east of the village, in Hereford Township, Berks County, probably were the largest, having a total production of about 250,000 tons. The ore deposits are near the contact of granite gneiss with a more basic igneous gneiss. Another well known mining district in the pre-Cambrian ores of Berks County is the Rittenhouse Gap group of mines one mile west of Seisholtzville. Here four parallel veins or zones of mineralization are known and are similar to the veins in the Vera Cruz area. The Wickert (65,000 tons), the Jobst (40,000) and the Wieland or Maun (100,000) mines were among the large producers in the eastern part of the pre-Cambrian belt.

Triassic magnetite deposits.
(Cornwall type)

The Cornwall type of deposit has supplied nearly all the iron ore mined in Pennsylvania in recent years. The entire production has come from the Cornwall mines after 1928 when the French Creek mines at Saint Peter were closed; a few other mines contributed small amounts from time to time. Several reports of this type of deposit have been published, the most important of which are Second Pennsylvania Geological Survey, report C-2 (York, Adams, Cum-

[5] Miller, B. L., Mineral resources of Allentown quadrangle: Penna. Geol. Survey, Atlas 206, 1925.

berland and Franklin Counties), C-4 (Chester County), D-3, vol. II (Berks County) and the Annual Report for 1885 (Cornwall deposits, Lebanon County). A. C. Spencer studied the Triassic deposits as a whole and described them in a paper[6] which gives the most complete data available for the majority of the deposits. In the last few years the French Creek[7] and the Cornwall[8] deposits have been described in great detail.

Since this type of deposit alone is worked in Pennsylvania and gives promise of predominating for many years, it will be discussed in more detail than other types. First the general characteristics will be brought out, then the deposits will be considered individually.

A contact metamorphic origin is ascribed to the Triassic magnetite deposits by all modern investigators; that is, the deposits were formed as an after effect of the intrusion of an igneous magma. The basic type of igneous rock, which is called diabase when it is fine grained and gabbro when it is coarse grained, during the process of cooling and crystallization following its intrusion, gives off hot solutions, either liquid or gaseous, which carry silica and iron. If these solutions enter a limestone, replacement of the calcium-magnesium carbonates by iron oxide takes place. The Triassic magnetite ore bodies are all adjacent to diabase intrusions and lie within the zone in which the country rock has been altered through the heat of the intruded diabase magma. In addition nearly all are definitely associated with limestone beds within this zone of alteration. Several different limestones occur along the borders of the Triassic intrusions and ore bodies have been found in all of them. They are the pre-Cambrian Franklin limestone (French Creek ore body), Cambrian Tomstown dolomite (Boyertown ore bodies), Ordovician Conococheague limestone (Cornwall ore bodies), and the Triassic limestone conglomerate (Dillsburg ore bodies).

Having established from the genesis of these deposits that they must be near diabase intrusions and replacing limestones, the search for new ore bodies is narrowed down to those strata which may contain limestone beds and which are in contact with diabase. Therefore it is economically possible to undertake intensive prospecting for deposits which are not exposed at the surface, whereas such methods would not be applicable if the ore bodies occurred in a great variety of geological environments.

In the descriptions of the individual deposits that follow, the mines and mining methods in use at each deposit will not be described. The size, shape and geographical location of the deposits will be considered as well as the geological environment, because all are useful in considering the future exploitation of the deposits.

The Cornwall ore bodies are 5 miles south of Lebanon. They lie

[6] Spencer, A. C., Magnetite deposits of the Cornwall type in Pennsylvania: U. S. Geol. Survey, Bull. 359, 1908.

[7] Smith, L. L., Magnetite deposits of French Creek, Pennsylvania: Penna. Topog. and Geol. Survey, Bull. M-14, 1931.

[8] Callahan, W. H., and Newhouse, W. H., A study of the magnetite orebody at Cornwall, Pennsylvania: Econ. Geol., vol. XXIV, pp. 403-411, 1929.

Hickok, W. O., 4th, The iron ore deposits at Cornwall, Pennsylvania: Econ. Geol., vol. XXVIII, No. 3, pp. 193-255, 1933.

along the hanging wall of a thick diabase dike which intrudes the Conococheague limestone. The dike extends roughly east-west and dips south at a steep angle. The limestone containing the ore bodies lies along the south flank of the diabase. It is cut off to the south by Triassic sandstone and shale and so lies in a narrow pocket between diabase and impervious shale. An impervious cover of limy shale formerly lay above the limestone in which the ore is found. These conditions made the pure carbonate rock an excellent place for the concentration of the exhalations from the solidifying diabase magma. Once they had escaped from the diabase the exhalations could not move rapidly through the limestone because of the impervious layers beyond and so deposited the greater part of their solid material in a small area. In this way the large compact ore bodies at Cornwall were formed.

The Wheatfield deposits lie about 7 miles southwest of Reading. There are several small ore bodies but no large ones. The geology is similar to that at Cornwall. A diabase dike extends east-west with a steep southern dip. Conococheague limestone lies south of the diabase and parts of it have been converted into ore by contact metamorphic action. The lack of impervious Triassic shales on the south may account for the small size of ore bodies. The diabase dike is thinner than at Cornwall.

The Raudenbusch deposit is about 2 miles south of Reading and half a mile west of the Schuylkill River. The ore bodies lie north of the diabase and are in limestone. The mine has been abandoned for a great many years and the only knowledge of the geology comes from very early investigators. The mine was small, never yielding over 5,000 tons of ore a year.

The Fritz Island deposits lie in the same belt as the Raudenbusch and were exposed on an island in the Schuylkill River 2 miles south of Reading. At this point three parallel diabase dikes cut across the Triassic shale and limestone conglomerate lying unconformably over the Conococheague limestone. The ore bodies are in the Conococheague limestone on the north flank of the northern dike. Between the three dikes only Triassic rocks show on the surface but it is probable that limestone lies a short distance under the surface and may contain additional ore deposits.

The Boyertown deposits are under and just south of Boyertown, Berks County. The ore bodies are in the Tomstown dolomite which lies under a cover of Triassic limestone conglomerate. They are tubular, representing certain beds in the dolomite that have been replaced by means of hot aqueous solutions from the near-by diabase sill. Some of the ore bodies are in direct contact with the diabase but not the uppermost body lying directly under the limestone conglomerate. Faults have offset some of the ore bodies, thus increasing their apparent number.

The Jones and Kinney mines are in southern Berks County three-quarters of a mile east of Joanna and 1¼ miles northwest of Elverson. The ore lies in a small area of limestone that probably is the Tomstown dolomite. The limestone is cut off to the east and west

by diabase intrusions and disappears under a cover of Triassic sandstone to the north and south. The ore bodies are adjacent to the limestone-diabase contact.

The Warwick mine is at the eastern end of the town of Warwick, about 3 miles east of Elverson, in Chester County. The geology of the deposit is not clearly stated by the early investigators and the mine has been abandoned for so many years that little can be learned of its geology. The ore bodies lie south of and close to the same diabase dike that is associated with the Jones and French Creek deposits. The surface around the deposit is underlain by Brunswick shale of Triassic age, but whether the ore is in the shale or some underlying older limestone is not known.

The French Creek deposit is just north of St. Peters, Chester County. The eastern continuation of the diabase dike at the Jones and Warwick mines passes just south of the deposit. The ore was formed through alteration of a marble bed in the pre-Cambrian Pickering (Baltimore) gneiss where the marble was cut across by the diabase. The high grade of the ore may have been caused by the purity of the pre-Cambrian marble.

The Dillsburg deposits in York County lie just east of Dillsburg. This group of ore bodies has the greatest areal extent of any of the Triassic magnetite deposits. More than thirty openings have been made to extract ore which is distributed throughout an area 1½ miles long and half a mile wide. In spite of the large size of the area, production has never been large and the quantity of ore recovered is estimated at 1,500,000 tons. The ore bodies are closely associated with diabase; nearly all the available mine maps and sections show some part of the ore in contact with the diabase. Although the data on hand fail to show that the ore invariably was formed by replacement of Triassic limestone conglomerate, nevertheless a great part of the ore was so formed and it seems logical to assume that all of it was. The individual deposits are not large or continuous and insufficient exploratory work has been done to determine the distribution and size of the beds of limestone conglomerate or the extent to which they have been converted into ore.

Ore bodies similar in occurrence to those at Dillsburg formerly were worked south of Grantham and 2 miles west of Wellsville in York County.

IRON CARBONATE DEPOSITS

Carbonate iron ores occur throughout the Paleozoic rocks of Pennsylvania but are more abundant in the younger strata of the western part of the State. The deposits have been divided into groups on the basis of the age of the rocks with which they occur.

The Cambro-Ordovician deposits are in or along the flanks of the great limestone valleys of central and southeastern Pennsylvania. They have never received much notice as invariably they are associated with the brown-ore deposits of these valleys; the carbonate ore nearly always was mined and shipped as brown ore. One analysis

by A. S. McCreath[9] of sorted lumps of carbonate ore from the Wharton mine, Northampton County, gives the following percentages: Fe 43.05, Mn 2.52, S 0.045, P 0.115, insoluble residue 2.11. Iron carbonate nodules can be found in the deeper parts of all the brown-ore deposits that are accessible at present and apparently extend to greater depths than the brown ore. No data are available about the greatest depth at which the iron carbonate occurs or about the size and shape of the deposits. It is believed[10] that the carbonate was formed by precipitation of iron from deep underground circulation of surface water which had picked up iron released during the weathering of the overlying rocks.

The Siluro-Devonian deposits lie chiefly in the Marcellus group. In the several localities thin limestone beds have been transformed into siderite by the addition of iron. Marcellus ore has long been mined in Carbon County for use in making paint. The ore bed averages 1½ feet thick. An average of several analyses[11] gives these percentages: Fe 33, Mn 0.01, SiO_2 25, CO_2 25. The ore also contains small amounts of lime, magnesia, sulphur and phosphorus.

The Mauch Chunk ore horizon lies within 15 feet of the top of the Mauch Chunk red beds directly under the Pottsville conglomerate. The best development of the ore occurs in the western part of the State, where three or four beds of carbonate, which are about 3½ feet thick in the aggregate, have been worked in many of the counties. Some of the ore is the kidney type, iron carbonate concretions mixed with a great deal of shale. At the points where ore was formerly mined, however, the ore beds are commonly nearly pure iron carbonate. The siderite from this formation, together with the weathered brown ore along its outcrop, supplied a large part of the ore for the early iron-smelting industry of western Pennsylvania. Very large quantities of it are still unmined. Analyses are given to show the grade of the ore:

Analyses of Mauch Chunk ore[12]

	1	2	3
Fe	31.10	41.00	42.50
S	.09	.19	.15
P	.10	.12	.13
Insoluble residue	25.95	6.81	7.11

1. Freemans mine, Mt. Pleasant Township, Westmoreland County.
2. Vernon mines, Bullskin Township, Fayette County.
3. Center Furnace mines, Wharton Township, Fayette County.

The carbonate ores in the Pottsville series lie in the Mercer horizon. As many as three thin beds of ore have been found in an interval of 30 to 50 feet. This ore in the past has been mined in Lawrence, Fayette and Somerset Counties.

[9] McCreath, A. S., Chemical analyses: Second Penna. Geol. Survey, vol. MM, p. 188, 1879.

[10] Miller, B. L., Mineral resources of the Allentown quadrangle: Penna. Geol. Survey Atlas of Pennsylvania, No. 206, 1926.

[11] Agthe and Dynan, Paint ore deposits near Lehigh Gap, Penna.: U. S. Geol. Survey, Bull. 430, p. 449, 1910.

[12] McCreath, A. S., Chemical analyses: Second Penna. Geol. Survey, Report MM, pp. 185-187, 1879.

In the Allegheny formation, siderite has been found at several horizons. The beds are commonly thin and not persistent. The Freeport limestone horizon formerly yielded iron carbonate in Allegheny, Indiana, Beaver and Somerset Counties. Likewise the Johnstown cement rock and the Vanport ("ferriferous") limestone are rich enough in iron in a few places to be low-grade ore.

The Conemaugh deposits are scattered throughout the Conemaugh group, but few, if any, of the ore horizons are extensive. The best horizons are the Brush Creek limestone, the Pittsburgh red beds and the Ames limestone. The iron carbonate commonly occurs in concretions when found in this group. In the Johnstown area the early iron industry was based on an ore bed 50 feet above the Upper Freeport coal. Deposits formerly were mined in the Brush Creek limestone in Beaver County and in the Ames limestone in Indiana County.

Iron carbonate occurs in the under clay of the Pittsburgh coal bed in Fayette County. Four thin beds of carbonate are persistent throughout a large part of the county. The ore averages 35 to 40 percent iron and is low in phosphorus and sulphur.

In the strata above the Pittsburgh coal many outcrops of iron carbonate have been noted in western Pennsylvania. None of the beds are extensive, however, and as the ore occurs as scattered concretions of siderite in shale, much waste must be moved to obtain the siderite. Furthermore the carbonates from these horizons commonly are high in phosphorus.

Down to 1880 Pennsylvania was a large producer of all classes of iron ore, the rank being brown ore, magnetite, hematite and carbonate. Hematite production had ceased by 1915. Brown ore and carbonate ore are no longer used for iron smelting; until recently a small tonnage found other uses, as in paint making. Magnetite production decreased until about 1915, then increased and reached its peak in 1927; after that it decreased, owing to market conditions, but in 1936 had again reached a production of 1,131,682 tons.

A few years ago a type of brown ore called bog ore was mined and used in removing sulphur from artificial gas. (See Table I.) The production of carbonate ores for smelting ceased about 1900 but from 1920 until recently a deposit near Palmerton, Carbon County, has been used in paint making.

Part II

ECONOMICS OF IRON ORE

PENNSYLVANIA'S IRON ORE MARKET

Although the production of iron ore in Pennsylvania has decreased somewhat in volume and greatly in relation to production in the United States, the consumption has not followed suit but has increased more than tenfold. This means that there is a nearby market for all the iron ore that may be produced in Pennsylvania, and that Pennsylvania ore has a price advantage determined by the difference in the costs of shipping the domestic and the out-of-State ores to the blast furnaces.

Figures for the consumption of iron ore are available for recent years only, so those for the production of pig iron will be used in their place. Iron ore consumption is roughly equal to twice the pig iron production. Two tons of ore make one ton of pig iron. Table II is arranged to show the relations of the iron ore and pig iron production in the United States and in Pennsylvania from 1850 to 1930. It also shows the ratio of iron ore production in Pennsylvania to the consumption as shown by pig iron production.

Statistics of production.

Production, value and price of Pennsylvania iron ores for selected years form Table I:

Three columns of Table II present the past and present status of the iron ore mining industry in Pennsylvania. The second column shows a decreasing production of iron in Pennsylvania from 1870 to 1915 and an increasing production from 1915 to 1930. The third column shows that Pennsylvania, once the dominant ore producer in the United States, has become a very small factor in iron-ore mining; she produced less than 3 percent of the iron ore mined in the United States in 1936 and for several years less than 1 percent. Statistics on pig iron are given in three columns of Table II. Two columns show that the United States and the Pennsylvania productions increased steadily throughout most of the period covered by this study. That the United States production has increased more rapidly than that of Pennsylvania can be seen in the column showing percentage of production. Pennsylvania's less rapid increase is due to the tendency of a growing business to spread with its markets rather than to any great natural advantages enjoyed by other sections of the United States.

The last column is arranged to contrast the production and consumption of iron ore in Pennsylvania. The theoretical ratio of 2 tons of iron ore to produce one ton of pig iron is used as a base of comparison. In the years 1860 and 1870 Pennsylvania was producing all the iron ore that it consumed. The slight excess of ore over the theoretical ratio shown by the table for these years may be due to exports of ore from the State, but it seems more probable that it

TABLE I

PENNSYLVANIA IRON ORE PRODUCTION BY CLASSES

(Long tons)

Year	Hematite	Brown Ore	Magnetite	Carbonate	Total	Value	Price per ton
1880[a]	267,572	1,009,550	498,146	176,227	1,951,495	$ —	$ —
1889[a]	162,957	496,555	860,916	39,806	1,560,234	3,063,534	1.96
1895[b]	87,711	221,654	582,406	5,707	897,478	1,303,130	1.45
1900[b]	28,101	202,161	593,346	2,716	826,324	1,308,246	1.58
1905[b]	17,591	189,146	536,021	50	742,808	1,104,180	1.49
1910[b]	12,082	101,473	613,758	—	727,313	964,370	1.33
1915[b]	4,710	32,086	425,860	—	462,656	468,615	1.01
1920[b]	—	7,256	590,052	748	598,056	661,055	1.11
1925[b]	—	1,034	732,828	2,956	736,818	1,521,424	2.07
1930[b]	—	228	1,067,209	1,855	1,069,292	2,337,517	2.18
1931	—	—	367,299	818	368,117	769,365	2.09[c]
1932	—	1,640	100,721	477	102,838	204,648	1.99[c]
1933	—	640	263,227	499	264,366	528,732	2.00[c]
1934	—	864	523,793	640	525,297	1,050,594	2.00[c]
1935	—	—	978,951	687	979,638	1,959,276	2.00[c]
1936	—	—	1,131,682	533	1,132,215	2,264,430	2.00[c]

[a] Represents figures for a single year.

[b] Represents average yearly production for preceding 5 years.

[c] Magnetite only.

TABLE II

COMPARISON OF PENNSYLVANIA AND UNITED STATES PRODUCTION OF IRON ORE AND PIG IRON

Year	Iron ore			Pig iron			Ratio of pig iron produced, to iron ore in Pennsylvania (Theoretical ratio 2 : 1.000)	
	United States production *Long tons*	Pennsylvania production *Long tons*	Percentage of U. S. production in Pennsylvania	United States production *Long tons*	Pennsylvania production *Long tons*	Percentage of U. S. production in Pennsylvania	Ore	Pig Iron
1840	—	—	—	286,903	98,395	34.3		—
1850	1,579,310	877,283	55.5	—	—	—		—
1860	3,218,275	1,351,000	42.0	821,223	580,049	70.6	2 :	.858
1870	4,303,847	2,337,286	53.8	1,665,179	1,033,272	62.1	2 :	.885
1880	7,120,362	1,951,495	27.4	3,835,191	1,893,655	49.1	2 :	1.938
1889[a]	14,518,011	1,560,234	10.74	7,603,642	3,801,281	50.0	2 :	4.875
1895[b]	14,062,533	897,477	6.38	8,133,033	3,992,106	49.1	2 :	8.90
1900[b]	21,038,708	826,324	3.93	11,491,937	5,423,689	48.2	2 :	13.13
1905[b]	33,926,273	742,808	2.18	18,239,655	8,381,201	45.96	2 :	22.59
1910[b]	48,752,572	727,313	1.49	24,224,721	10,354,951	42.77	2 :	27.51
1915[b]	51,594,677	462,656	0.894	21,544,976	11,387,443	52.9	2 :	49.40
1920[b]	69,736,937	598,056	0.858	37,010,401	14,370,090	38.7	2 :	48.03
1925[b]	52,429,273	736,818	1.404	30,475,106	10,640,588	35.3	2 :	28.91
1930[b]	64,599,514	1,069,292	1.654	37,692,048	12,074,020	32.04	2 :	22.60
1931	31,131,502	368,117	1.111	17,952,613	5,036,305	28.05	2 :	27.36
1932	9,846,916	102,838	1.044	8,549,649	2,103,170	24.59	2 :	40.88
1933	17,553,188	264,366	1.506	13,027,343	3,733,570	28.66	2 :	28.24
1934	24,587,616	525,297	2.132	15,686,442	4,244,566	27.05	2 :	16.16
1935	30,540,252	979,638	3.207	20,827,196	5,479,792	26.31	2 :	11.18
1936	48,788,745	1,132,215	2.321	30,254,022	9,105,058	30.09	2 :	16.08

[a] Figures for 1890 are incomplete so 1889 is used.

[b] Average yearly production for 5 years preceding date.

was caused by the use of low-grade iron ore which would require more than two tons of ore to produce one ton of pig iron. Beginning with 1880 importation of iron ore into Pennsylvania can be seen from the ratios for the various years. From 1880 to 1920 the importation of ore for Pennsylvania consumption steadily increased. A change set in soon after 1920, however, and now imports appear to be decreasing and the ratio of the consumption of Pennsylvania ore to imported ore increasing.

OTHER SOURCES OF IRON ORES

Before the low-grade iron ores of Pennsylvania become valuable again the high-grade ores which have displaced them from the market must be largely exhausted. For this reason it seems well to include here a brief survey of the out-of-State ore resources. First the deposits that are actively competing with the Pennsylvania ores will be considered. They will be followed by a discussion of the deposits which, it seems probable, will compete in the future.

Lake Superior. The Lake Superior iron ore deposits are situated in Minnesota, Wisconsin and Michigan, with by far the largest reserves in the Mesabi Range, in Minnesota. The tax commissions of Minnesota and Michigan each year estimate the reserve tonnages of merchantable ore in the various mines and calculate the totals for the States. In Wisconsin, tax commission figures are not published and estimates of ore reserves are less accurate.

Iron ore reserves (tons)	
Minnesota	1,242,000,000
Michigan	169,000,000
Wisconsin	23,000,000
Total reserves	1,434,000,000

This tonnage of iron ore will last 28 years at the present rate of consumption but if the present increase in consumption continues, it is sufficient for only 23 years. The discovery of new reserves and the extension of old deposits will somewhat lengthen the life of the district, probably bringing it up to 30 years or more for mining ore of the present grade. However as the grade of the ores shipped gradually becomes lower throughout this period, more and more of the deposits that at present are too lean, will be included in the reserves, especially as it is becoming possible to beneficiate the lower grade ores at little additional cost so that they can be shipped more cheaply. Iron mining in the district will not cease suddenly. Nevertheless, even if the price of ore per ton should not increase but remain at the present figure ($4.95 to $5.25, Feb. 1939), the price per unit of iron will have risen gradually through the decrease in the grade of the ore. The result will be that competition from the high-cost ores which are now excluded from the market will begin to be felt by the Lake ores, the rapid consumption of Lake ores will gradually diminish, and the life of the district will be indefinitely extended, but will be of less significance to Pennsylvania ores than at present.

Alabama. In the mountains around Birmingham, Alabama, large deposits of ore carry 35 to 40 percent iron. This low-grade ore is valuable because it is near coking coal and is largely self-fluxing. The present production is 4,000,000 tons a year and the reserves are about 1,500,000,000 tons. This will give the district a very long life even if production increases materially. However, owing to the low grade of the ore, it seems unlikely that ore will be shipped to Pennsylvania in the near future, if at all. Therefore, Alabama iron ore need not be counted at present in a study of the future of the Pennsylvania iron-ore mining industry.

Cuba. The Cuban iron ore deposits are of two types. The first produces hard ore with a high iron content. Deposits of this type lie along the southeast coast of Cuba, but as they are nearly exhausted, they will be of little importance in the iron ore markets of the future. The second type is a low-grade surface accumulation of iron oxide and hydroxide covering large areas on the eastern end of the island. This ore can be nodulized cheaply but the problem of making it anything like "standard ores" has not been solved. It will some day constitute a very large reserve. Over 2,500,000,000 tons are known to exist. Most of this ore is owned by the Bethlehem Steel Company and probably it will be used in the United States. The ore contains nickel and chromium in small quantities. These are detrimental to its use for making pig iron but help in making certain kinds of steel. Imports of iron ore from Cuba in 1937 were 441,500 gross tons.[13]

Chile. The iron-ore deposits in Chile are high grade. They also are operated by Bethlehem Steel Company and the ore is shipped to the United States through the Panama Canal. Chile is the chief source of imported iron ore, furnishing 1,438,886 gross tons in 1937, or 59 percent of the total. Estimates of the Chilean reserves are not available.

The following great deposits at present supply the American consumers with little iron ore. However, slight increases in the price along the Atlantic seaboard will make it profitable to import these ores.

Brazil. Exports of iron ore from Brazil are very small owing to poor transportation facilities from the deposits to the sea and to the attitude of the Brazilian government towards the depletion of natural resources. Conservative estimate of the high-grade iron ore reserves gives 3,500,000,000 tons as the probable figure, whereas other estimates run as high as 8,000,000,000 tons. The ore is very desirable because of its high iron and low phosphorus content. Such a gigantic deposit could supply the entire world with iron for 50 to 100 years at least. Imports of Brazilian ore into the United States in 1937 were 11,000 tons.

[13] U. S. Bureau of Mines, Minerals Year Book, 1938, p. 496.

Venezuela. Venezuela, although producing no iron, has large reserves which are accessible to ocean transport. No figures have been compiled for the total iron ore in all the deposits known but exploration work carried on in some of the districts has developed large tonnages of very high-grade iron ore. Although not as large as the Brazilian deposits, Venezuela will contribute to the world supply of iron ore.

Newfoundland. The Newfoundland deposits have been producing iron ore for many years. These deposits are exceptional in that the iron is loaded directly into ocean steamers at the mine mouth. Owing to the fact that the ore beds lie under Conception Bay, the reserves cannot be explored by surface drilling, but they are known to be large and probably are limited only by the distance underground to which mining can be carried profitably. Imports of iron ore from Newfoundland and Labrador in 1937 were 45,080 gross tons.

Sweden. The Kirunivarra and other smaller ore deposits of northern Sweden have an annual production of 5,000,000 tons. The ore, which is high in phosphorus, is chiefly consumed in Germany, but production could readily increase to supply the United States if there were sufficient demand. The reserves of these deposits are very large; they are estimated at 1,150,000,000 tons lying within 1,000 feet of the surface, with still greater tonnages at greater depth. Imports of iron ore from Sweden in 1937 were 150,223 gross tons and of Swedish ore through Norway were 252,657 tons.

France. The Minette iron-ore deposits of France and Luxemburg rank among the largest in the world, and although the ore is of comparatively low grade, their position near the great European coal mines makes them very valuable. They will continue to supply central Europe with iron ore for many years, but, probably, will never compete in the United States markets.

Russia. The extent of Russian ore deposits is largely a matter of conjecture but it can be assumed that, although great in volume, in some cases high in quality, they will not be great factors in our market because of the long railroad haul to seaboard for ore from all but a few of the smaller Russian deposits. Imports of iron ore from U.S.S.R. (Russia) in 1937 were 5,100 gross tons.

Africa. North Africa will continue to be a moderate source of ore for export for many years. Imports of iron ore from Algeria in 1936 were 12,293 gross tons. South Africa has no known deposits so located as to be important for export. Furthermore South Africa has coal and is developing a steel industry that probably will use the local ores. West Africa is exporting iron ore from Sierra Leone. Iron-ore mining is capable of moderate development there.

India. With its enormous population and its coal and iron deposits, it is to be expected that India will make iron and steel and not export the raw materials.

Philippine Islands. 500,000 tons of Philippine iron ore went to Japan in 1937. New deposits are being developed. Exportation of ore probably will continue but it is doubtful if the ore will be shipped so far afield as the United States.

Australia. It is reported in 1938 that Australia is to discontinue exporting iron ore, on the ground that the ore is needed for use in that country. Our imports of Australian iron ore in 1937 were 79,588 gross tons.

Summary. If the exploitation of Pennsylvania iron ores depends upon the exhaustion of the available out-of-State high-grade ores it will be necessary to wait several scores or even hundreds of years. The one chance for a return of iron-ore mining in Pennsylvania in the present century seems to be the installation of concentrating plants which can treat the ore at a cost less than the difference between the freight rates from the high-grade ore deposits and from the low-grade Pennsylvania deposits.

CONCENTRATION OF IRON ORES

The term beneficiation is commonly applied to all the processes which are used to improve ores after they are mined and before they are smelted. It includes such treatments as crushing, screening and drying, as well as processes which separate the ore minerals from the gangue. Concentration includes only the type of process which directly increases the grade or tenor of the ore. Since only this latter type of treatment will serve to make the low-grade Pennsylvania iron ores merchantable, processes of concentration will be considered here.

The cost of smelting is much greater for low-grade iron ore than for high-grade ore because of the necessity for using greater amounts of coke and flux with the low-grade ore. It is usually more economical to concentrate the low-grade ore before smelting than to smelt it as mined. Concentration is generally done at or near the mine to reduce costs of shipment.

Many methods of ore concentration have been used but most of them are too costly for iron ore. At present magnetite and brown ore can be economically treated, but no methods are known for commercial concentration of hematite and carbonate ore. Brown ore is generally concentrated by washing the loose sand and clay from the limonite. Magnetite is separated from its gangue by means of magnetic separators. The details of methods of ore concentration can be found in any good book on ore dressing.

Although no commercial methods of concentrating hematitic or carbonate ores has yet been found, undoubtedly some will be developed

when a shortage of high-grade ores occurs in the Lake Superior region. At present there is insufficient stimulus to warrant extensive research along these lines.

The economic results of ore concentration are shown in Table III. In column 4 the value per ton of Pennsylvania iron ore is shown. In 1889 the price was $1.96 a ton and from that time until about 1920 it decreased until it was slightly over one dollar a ton. The reason for this decrease was the increasing ratio of low to high-grade ore included in the Pennsylvania production. The minimum prices were reached in the years 1912 to 1920 when Pennsylvania produced mostly low-grade magnetite ores. A change took place soon after 1920 and the value of ore rose above $2.00 a ton. This increase in price was due to the installation and operation of a concentrating plant to treat Cornwall ore.

TABLE III

Comparison of iron ore production in Pennsylvania with that of the Cornwall ore banks

Year	Pennsylvania production	Cornwall production	Percentage of Pennsylvania production at Cornwall	Price per ton of ore in Pennsylvania
1850	877,283			
1860	1,351,000			
1870	2,337,286			
1880	1,951,495			
1889	1,560,234	769,020	49.3	$1.96
1895	897,478	560,433	62.4	1.45
1900	826,324	582,143	62.4	1.58
1905	742,808	515,354	69.4	1.49
1910	727,313	596,278	83.3	1.33
1915	462,656	419,190	90.7	1.01
1920	598,056	566,622	94.7	1.11
1925	736,818	642,185	87.3	2.07
1930	1,069,292	1,021,451	95.5	2.18
1936	1,132,215	1,131,682	99.9	2.00

Figures for Pennsylvania production, 1895 to 1930, represent average yearly production for preceding five years.

WHAT WILL THE FUTURE BRING?

Pennsylvania can never hope to regain the predominant place it once held in the iron-mining industry of the United States, but it can achieve a greater yearly production of ore than ever attained in the past. The iron ore production of the United States has increased from a few million tons annually before 1875 to 49 million tons in 1936. This increase has been so great that the iron-ore resources of Pennsylvania could never hope to supply more than a small portion of it. However, that small portion may be large enough to give Pennsylvania an annual production far in excess of any annual production in the past.

At some time in the future all the high-grade iron ore deposits in the world may be depleted. Then it will be necessary to concentrate

all iron ore before it is smelted. However, before such a time arrives many of the favorably situated low-grade ore deposits will be producing concentrates which will compete successfully with the more distant high-grade ores.

At the present time low-grade concentrated magnetite ore from Cornwall is able to compete successfully in eastern Pennsylvania with high-grade iron ores from other districts. This deposit operates under more favorable circumstances than are possessed by any other known deposit in Pennsylvania. (The deposit is large and compact so that it can be mined cheaply and the ore is readily concentrated.) With the exhaustion of the more favorably located high-grade iron ore bodies and with the price of iron ore slowly rising in the future, Pennsylvania deposits which will have to operate under slightly less favorable conditions than the Cornwall mines should be able to produce iron ore at a profit.

In order to produce iron ore at a low cost, mining operations have to be undertaken on a large scale and large expenditures of capital are necessary for mining, hauling, hoisting, and loading equipment. Before investing these large amounts of capital in a mining venture it is advisable to explore the ore deposit thoroughly to ascertain if there will be sufficient good quality ore to assure the return of the invested capital and a reasonable profit. This assurance can be obtained by means of geological investigation of the deposits and by core drilling which show the exact size of the ore body and the quality of the ore.

As all Pennsylvania ore should be concentrated before it is shipped far from the mine, the erection of a concentrating plant becomes a necessary adjunct to any mining venture. Before such a plant is built there must be reasonable certainty that sufficient ore occurs nearby to keep the plant operating for a long period of years in order to pay the cost of its erection. Bearing all the above facts in mind it can be seen that future iron-ore mining in Pennsylvania will differ from that in the past. Formerly many individual operators opened small mines and operated them without the advantage of labor-saving machinery, and a knowledge of the size and shape of the deposit. In the future there will be a smaller number of mines which will operate on a large scale, producing large tonnages of ore at a much lower cost per ton than can be done by small operators.

Let us consider which classes of Pennsylvania iron-ore deposits are the most favorable for future exploitation. The hematite and carbonate deposits, aside from the fact that methods are now unknown for the commercial concentration of such ore, are not well suited for future exploitation as the deposits are tabular in form and the ore beds are so thin that considerable nonferrous material must be extracted with the ore. Therefore, the costs of mining will be high, and low cost mining is a prime requisite for ore that is to be concentrated. In addition, the character and grade of the ore in a single bed changes in closely spaced intervals so that mining the ore becomes more difficult and expensive than it would be if the ore was homogeneous over long distances.

The brown iron ore resources of Pennsylvania have been exhausted to such an extent that they do not form a large reserve. Several large very low grade deposits remain and will be mined eventually. All the high-grade deposits are exhausted and those that remain are low-grade deposits which require the digging of several tons of lean ore to obtain one ton of concentrates. The concentration, as well as the digging of this ore, can be accomplished cheaply so that the very low grade of the ore can be overcome wherever the deposits are large. However, as digging the ore ruins the land under which it is located for future cultivation, the agricultural value of the land must be included in the mining cost and in some places this item is high owing to the large areal extent of the deposits. This type of deposit is available for exploitation whenever the price of iron ore has risen to a point high enough to pay for the mining and the concentration of the ore.

The magnetite deposits are of moderate to large size, which makes possible the installation of adequate equipment for economical mining. The ore bodies are compact and massive rather than lenticular or in a thin bed, so that mining costs may be held at a minimum. The ore mineral is magnetic so that concentration may readily be accomplished. Many of the deposits carry minerals such as pyrite and chalcopyrite which can be extracted as by-products during concentration and thus increase the return on the deposit. In addition, this type of deposit is more readily explored before mining than any of the others. Magnetic and geologic surveys can direct core drilling so that the extent of the deposit is ascertained without needless expense. Thus all the circumstances most favorable to successful exploitation point to magnetite deposits as being the type which are most susceptible to mining in Pennsylvania.

In conclusion, we must not look for a return of small expensive-to-operate mines which are worked as dictated by the whim of the miner, but to the opening up of large deposits which are scientifically mined by cheap methods. The low-grade iron ore of the State must be treated in concentrating plants before shipment to the furnace. The revival of iron-ore mining in Pennsylvania will not happen over night with the sudden exhaustion of the present source of iron-ore supply, the Lake Superior region, but may return gradually as the slowly rising price of iron ore will make possible the profitable mining of the low-grade Pennsylvania deposits.

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